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(54) **MOLTEN CARBONATE FUEL CELL ANODE EXHAUST POST-PROCESSING FOR CARBON DIOXIDE CAPTURE**

ABGASNACHVERARBEITUNG EINER SCHMELZKARBONAT-BRENNSTOFFZELLENANODE ZUR KOHLENDIOXIDABSCHEIDUNG

POST-TRAITEMENT D'ÉCHAPPEMENT D'ANODE DE PILE À COMBUSTIBLE À CARBONATE FONDU POUR LA CAPTURE DE DIOXYDE DE CARBONE

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Description

BACKGROUND

[0001] The present disclosure relates to carbon dioxide (CO_2) separation in direct molten carbonate fuel cells ("DFC"). In particular, the present disclosure relates to an electrochemical hydrogen separator ("EHS") receiving a CO_2-rich anode exhaust stream from a DFC and concentrating the CO_2 for sequestration.

[0002] In a CO_2 separation system for a DFC, the CO_2-rich anode exhaust stream also contains water vapor and unused fuel, including mostly hydrogen and carbon monoxide (CO). To make the stream ready for CO_2 capture (i.e., separation) for sequestration or use, some processing or post-treatment is required.

[0003] US 2008/0241612 A1 discloses a method of operating a fuel cell system including providing a fuel inlet stream into a fuel cell stack, operating the fuel cell stack to generate electricity and a hydrogen containing fuel exhaust stream, separating at least a portion of hydrogen contained in the fuel exhaust stream using a cascaded electrochemical hydrogen pump, such as a high temperature, low hydration ion exchange membrane cell stack having at least two membrane cells arranged in a process fluid flow series, and providing the hydrogen separated from the fuel exhaust stream into the fuel inlet stream.

[0004] US 2004/0028979 A1 discloses a method and apparatus for electrochemical compression and expansion of hydrogen in a fuel cell system.

SUMMARY

[0005] In a first aspect of the invention, there is provided a fuel cell system according to Claim 1.

[0006] In a second aspect of the present invention, there is provided a method according to Claim 7.

[0007] In a third aspect of the present invention, there is provided a method according to Claim 10.

[0008] In a third aspect of the present invention, there is provide a method according to Claim 12.

[0009] In a fourth aspect of the present invention, there is provided a method according to Claim 14.

[0010] According to the invention, the fuel cell system includes a first fuel cell having a first anode and a first cathode, wherein the first anode is configured to output a first anode exhaust gas. The system further includes a first oxidizer configured to receive the first anode exhaust gas and air from a first air supply, to react the first anode exhaust gas and the air in a preferential oxidation reaction, and to output an oxidized gas. The system further includes a second fuel cell configured to act as an electrochemical hydrogen separator ("EHS"). The second fuel cell includes a second anode configured to receive the oxidized gas from the first oxidizer and to output a second anode exhaust gas, and a second cathode configured to output a hydrogen stream. The system further includes a condenser configured to receive the second anode exhaust gas and to separate water and CO_2.

[0011] According to the invention, the method of processing fuel cell exhaust includes, at a first oxidizer, receiving a first anode exhaust gas from a first anode of a first fuel cell and air from a first air supply, and outputting an oxidized gas from the first oxidizer. The method further includes, at a second fuel cell having a second anode and a second cathode, receiving the oxidized gas at the second anode, electrochemically separating hydrogen in the oxidized gas, outputting a hydrogen stream from the second cathode, and outputting a second anode exhaust gas from the second anode.

[0012] These and other advantageous features will become apparent to those reviewing the disclosure and drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

[0013]

FIG. 1 shows a schematic view of a fuel cell system including a CO_2 sequestration subsystem using an electrochemical hydrogen separator, according to an exemplary embodiment.

FIG. 2 shows a schematic view of a fuel cell system including a CO_2 sequestration subsystem using an electrochemical hydrogen separator, according to another exemplary embodiment.

FIG. 3 shows a schematic view of a fuel cell system including a CO_2 sequestration subsystem using a pressure swing adsorption unit, according to an exemplary embodiment not forming part of the invention.

FIG. 4 shows a schematic view of a fuel cell system including a CO_2 sequestration subsystem using a pressure swing adsorption unit, according to another exemplary embodiment not forming part of the invention.

DETAILED DESCRIPTION

[0014] Referring generally to the figures, disclosed herein is a fuel cell subsystem for post-processing fuel cell anode exhaust gas to provide CO_2 sequestration.

[0015] Conventionally, combustibles in an anode exhaust gas may be reacted in an oxidizer. Oxygen rather than air is supplied to the oxidizer because nitrogen present in air may dilute the CO_2 in the anode exhaust gas. An air separation subsystem must be incorporated to provide the necessary oxygen to the oxidizer. However, when using oxygen, water is injected as a coolant in the oxidizer to maintain the oxidizer at a desired temperature level (e.g., to avoid overheating a catalyst). The oxidizer generates an oxidizer exhaust including at least water and CO_2. Heat generated in the oxidizer is then

used to preheat a cathode inlet stream. After recuperative heat exchange, the anode exhaust/oxidizer exhaust stream is cooled down in a condenser to remove water. A condenser downstream from the oxidizer separates and removes the injected water and any other water present in the exhaust stream, generating oxidizer exhaust with a higher concentration of CO_2 ready for sequestration. In one example, when feeding oxygen to an oxidizer in a fuel cell system using greenhouse gas ("GHG") from a pulverized coal ("PC") boiler steam cycle power plant, the CO_2 stream for sequestration contains approximately 89% CO_2 and 10% water, with 74% fuel utilization. When air is fed to the oxidizer rather than oxygen, the CO_2 content is reduced to approximately 58%.

[0016] Referring to FIG. 1, a post-treatment system is shown according to an exemplary embodiment. The process includes recovering hydrogen such that, after providing the required heat to a the cathode inlet stream, excess hydrogen is isolated as a co-product. According to another exemplary embodiment, the excess hydrogen is recycled to a DFC anode as supplementary fuel.

[0017] A fuel cell system 1 includes a first fuel cell 10 having a cathode 12 (i.e., a first cathode) and an anode 14 (i.e., a first anode). According to an exemplary embodiment, the first fuel cell 10 may be a DFC. The anode 14 outputs an anode exhaust gas, including at least CO_2, hydrogen, water, and CO. A first heat exchanger 20 receives the anode exhaust gas from the DFC and partially cools the anode exhaust gas. The first heat exchanger 20 then outputs a first partially-cooled gas. The first partially-cooled gas is transformed through a high-temperature ("HT") CO shift reaction (e.g., water-gas shift reaction) in a first shift reactor 21, forming a first shifted gas, which is received by a second heat exchanger 22. The first shift reactor 21 is configured to operate at a first temperature in a range of approximately 310°C to 450°C. The first shift reactor 21 may be configured to shift CO and water into CO_2 and hydrogen, such that the first shifted gas has a higher concentration of CO_2 and hydrogen than the first partially-cooled gas. The second heat exchanger 22 partially cools the first shifted gas and outputs a second partially-cooled gas. The second partially-cooled gas is transformed through a low-temperature ("LT") CO shift reaction in a second shift reactor 23, forming a second shifted gas, which is received by a third heat exchanger 24. The second shift reactor 23 is configured to operate at a second temperature in a range of approximately 200°C to 250°C, such that the first temperature is higher than the second temperature. The second shift reactor 23 may be configured to shift CO and water into CO_2 and hydrogen, such that the second shifted gas has a higher concentration of CO_2 and hydrogen than the second partially-cooled gas. The third heat exchanger 24 cools the second shifted gas to a desired temperature and outputs a cooled gas. According to an exemplary embodiment, the temperature of the cooled gas is based on a range of temperatures acceptable by an oxidizer 30 downstream from the third heat exchanger 24.

[0018] The cooled gas is mixed with air, rather than oxygen, which is provided (i.e., injected) by an air supply 26 (i.e., first air supply, controlled air supply, etc.), forming a mixed gas. According to an exemplary embodiment, the air supply 26 may be controlled to establish a preferred ratio of air to any one of CO_2, hydrogen, water, and/or CO making up the cooled gas. This preferred ratio may be based on the requirements of the oxidizer. The mixed gas is then fed to the oxidizer 30, which is configured to perform a preferential oxidation reaction for conversion of CO to CO_2. Preferential oxidation is a chemical process for removing CO. This process uses a low-temperature shift reactor (e.g., similar to the second shift reactor 23) followed by a staged preferential oxidizer for oxidizing CO using oxygen in the presence of a noble metal catalyst (e.g., platinum, palladium-cobalt, palladium-copper, gold, etc.). The oxidizer 30 outputs an oxidized gas containing CO_2 for sequestration and generates heat due to the reaction. A fourth heat exchanger 32 receives the oxidized gas from the oxidizer 30 and cools the oxidized gas, forming, at least in part, an anode inlet stream 34. According to an exemplary embodiment, the oxidizer 30 generates exhaust, separate from the oxidized gas containing CO_2. Because exhaust from the oxidizer 30 does not form part of the oxidized gas output, air may be used for the oxidizer, eliminating the need for an air separation unit and/or water injection (e.g., for oxidizer temperature control).

[0019] As shown in FIG. 1, the system 1 further includes an EHS 40 (also referred to as a second fuel cell). The EHS 40 includes a cathode 42 (i.e., a second cathode), an anode 44 (i.e., a second anode), and a proton exchange membrane ("PEM") 46 disposed between the cathode 42 and the anode 44. The anode 44 receives the cooled anode inlet stream 34 from the fourth heat exchanger 32. At the anode 44, at least a portion of the hydrogen present in the anode inlet stream 34 is selectively oxidized to positively charge hydrogen ions (H^+), which are then transferred to the cathode 42 through the PEM 46. Referring still to FIG. 1, in the cathode 42, H^+ is reduced to gaseous hydrogen due to the absence of an oxidant. Therefore, the EHS 40 selectively generates and outputs a hydrogen stream 50 from the anode inlet stream 34. The hydrogen stream 50 is generated as co-product and may be used in the system 1 or exported. According to an exemplary embodiment, each of the shift reactors 21, 23 are configured to maximize hydrogen recovery in the corresponding high-temperature and low-temperature CO shift reactions and prevent carbon monoxide poisoning of an EHS catalyst. According to another exemplary embodiment, the hydrogen stream 50 may be compressed (e.g., electrochemically), with relatively low energy input. Advantageously, the transfer across the PEM 46 utilizes a minimum energy input and does not require any moving parts. According to an exemplary embodiment, the EHS 40 may recover approximately 95% of the hydrogen from the anode exhaust gas from the

first fuel cell 10.

[0020] The anode 44 of the EHS 40 generates a second anode exhaust gas. The second anode exhaust gas is fed to a condenser 60, which separates the second anode exhaust gas into a CO_2 stream 61 and a water stream (i.e., condensate) 66. The CO_2 stream 61 from the condenser 60 is then fed through a CO_2 compressor 62 to liquefy at least a portion of the CO_2 stream 61, generating a highly concentrated CO_2 supply 64 suitable for sequestration and/or export (i.e., transportation) to a point of use (e.g., for food processing). According to an exemplary embodiment, after removal of water in the condenser 60 to the water stream 66, the CO_2 stream 61 includes approximately 89% CO_2 and approximately 9% water.

[0021] As shown in FIG. 2, at least a portion of the hydrogen stream 50 may be oxidized using air to generate heat, according to another exemplary embodiment. A first portion 51 of the hydrogen stream 50 generated by the cathode 42 of the EHS 40 is fed to an oxidizer 52 (i.e., a second oxidizer) and is oxidized with air from an air supply 54 (i.e., a second air supply). The oxidization generates an oxidized hydrogen stream 53, including at least heat and water and is fed through a fifth heat exchanger 56. The fifth heat exchanger 56 transfers heat from the oxidized hydrogen stream 53 to preheat a cathode inlet stream 36 (e.g., desulfurized GHG from coal-fueled power plants), received by the first cathode 12 of the first fuel cell 10. According to another exemplary embodiment, the oxidized hydrogen stream 53 may be used to preheat a cathode inlet stream received by the cathode 42 of the EHS 40 or any other cathode. The oxidized hydrogen stream 53 may then be outputted from the system 1.

[0022] In the embodiment shown in FIG. 2, the first portion 51 of the hydrogen stream 50 used to heat the cathode inlet stream 36 includes approximately 45% of the hydrogen generated by the cathode 42. The remaining second portion 55 (e.g., approximately 55% of the hydrogen stream 50) is generated as co-product and may be used in the system 1 or exported. The percentage of the hydrogen stream 50 forming each portion 51, 55 may vary according to other exemplary embodiments. According to an exemplary embodiment, the first portion 51 of the hydrogen stream 50 may be limited to an amount necessary to provide a desired level of preheat to the cathode inlet stream 36. According to another exemplary embodiment, the second portion 55 of the hydrogen stream 50 (e.g., hydrogen not fed to the second oxidizer 52 to preheat the cathode inlet stream 36) may be recycled (e.g., fed) to the first anode 14 of the first fuel cell 10, thereby reducing the natural gas fuel input required to operate the first fuel cell 10.

[0023] Referring now to FIG. 3, a post-treatment system is shown according to an illustrative example, which does not form part of the invention. In this system, as with earlier exemplary embodiments, hydrogen present in anode exhaust gas is separated and recovered.

[0024] A fuel cell system 100 includes a fuel cell 110 having a cathode 112 and an anode 114. The fuel cell 110 may be a DFC substantially same as the first fuel cell 10. The anode 114 outputs an anode exhaust gas, including at least CO_2, hydrogen, water, and CO. A first heat exchanger 120 receives the anode exhaust gas from the DFC and partially cools the anode exhaust gas. The first heat exchanger 120 outputs a first partially-cooled gas. The first partially-cooled gas is transformed through a high-temperature CO shift reaction in a first shift reactor 121, forming a first shifted gas, which is received by a second heat exchanger 122. The first shift reactor 121 is configured to operate at a first temperature in a range of approximately 310°C to 450°C. The first shift reactor 121 may be configured to shift CO and water into CO_2 and hydrogen, such that the first shifted gas has a higher concentration of CO_2 and hydrogen than the first partially-cooled gas. The second heat exchanger 122 partially cools the first shifted gas and outputs a second partially-cooled gas. The second partially-cooled gas is transformed through a low-temperature CO shift reaction in a second shift reactor 123, forming a second shifted gas, which is received by a condenser 160. The second shift reactor 123 is configured to operate at a second temperature in a range of approximately 200°C to 250°C, such that the first temperature is higher than the second temperature. The second shift reactor 123 may be configured to shift CO and water into CO_2 and hydrogen, such that the second shifted gas has a higher concentration of CO_2 and hydrogen than the second partially-cooled gas. The condenser 160 separates the second shifted gas into a dried (e.g., dehydrated) anode exhaust gas stream 161, containing at least CO_2 and hydrogen, and a separate water stream (i.e., condensate) 166. For example, substantially all of the water is removed from the anode exhaust gas stream when forming the dried anode exhaust gas stream 161. The dried anode exhaust gas stream 161 from the condenser 160 is then fed through a compressor 162, forming a compressed anode exhaust gas stream, which is then fed through a third heat exchanger 163, to further cool the compressed anode exhaust gas stream. The third heat exchanger 163 may be disposed upstream from the compressor 162 (e.g., between the condenser 160 and the compressor 162) and is configured to cool the dried anode exhaust gas stream 161.

[0025] The system 100 includes a pressure swing adsorption ("PSA") unit 170. The PSA unit 170 is configured to receive the compressed anode exhaust gas stream from the third heat exchanger 163 and separate the stream into a hydrogen stream 150 and a CO_2 stream 165. In the PSA unit 170, the gases other than hydrogen (e.g. mostly CO_2 and some water) are adsorbed by an adsorbent bed media at high pressures and a pure hydrogen stream 150 is outputted from the PSA unit 170 at a pressure close to (e.g., substantially the same as) an inlet pressure of the compressed anode exhaust gas stream received at the PSA unit 170. The hydrogen stream 150 is generated as co-product and may be used

in the system 100 or exported. After the adsorbent bed media in the PSA unit 170 reaches its maximum adsorbent capacity, it is purged to remove the adsorbed gases, which generate the CO_2 stream 165. This purging occurs by de-sorption, accomplished by lowering the pressure to near atmospheric pressure of approximately 20 psia. The CO_2 stream 165 is then fed to a CO_2 compressor 167 to liquefy at least a portion of the CO_2 stream 165, generating a sequestered CO_2 supply 164.

[0026] The system 100 may transform a portion of the hydrogen stream 150 in the same way as the hydrogen stream 50 as shown in FIG. 2. For example, as shown in FIG. 4, a first portion 151 of the hydrogen stream 150 generated by the PSA unit 170 is fed to an oxidizer 152 and oxidized with air from an air supply 154. The oxidization generates an oxidized hydrogen stream 153, including at least heat and water and is fed through a fourth heat exchanger 156. The fourth heat exchanger 156 transfers heat from the oxidized hydrogen stream 153 to preheat a cathode inlet stream 136 (e.g., desulfurized GHG from coal-fueled power plants), received by the cathode 112 of the first fuel cell 110. The oxidized hydrogen stream 153 may be outputted from the system 100. Similarly to FIG. 2, the first portion 151 of the hydrogen stream 50 may be limited to an amount necessary to provide a desired level of preheat to the cathode inlet stream 136. A remaining second portion 155 of the hydrogen stream 150 (e.g., hydrogen not fed to the oxidizer 152 to preheat the cathode inlet stream 136) may be recycled (e.g., fed) to the anode 114 of the fuel cell 110, thereby reducing the natural gas fuel input required to operate the fuel cell 110.

[0027] With regard to either system 1, 100, according to another exemplary embodiment, a process for sequestering CO_2 may include consuming all hydrogen and other combustibles in an oxidizer and utilizing the energy content for preheating a cathode inlet stream.

[0028] In certain embodiments, a fuel cell system includes a fuel cell having an anode and a cathode, an oxidizer, and an electrochemical hydrogen separator. The oxidizer is configured to receive anode exhaust gas from the anode and air from a controlled air supply and react the anode exhaust gas and the air in a preferential oxidation reaction. The separator is configured to receive oxidized gas from the oxidizer and to form separate streams of hydrogen and CO_2 from the remaining gas. A condenser is configured to receive the CO_2 stream from the oxidizer and condense the stream to separate water and liquefy CO_2.

[0029] In other illustrative examples, which are not part of the invention, a fuel cell system includes a fuel cell having an anode and a cathode, a condenser, and a pressure swing adsorption unit. The condenser is configured to receive and condense anode exhaust gas from the anode and separate a water stream from the remaining condensed gas. A compressor receives and compresses the remaining condensed gas and feeds compressed gas to the pressure swing adsorption unit. The pressure swing adsorption unit separates a hydrogen stream and a CO_2 stream. The CO_2 stream is received by a second compressor configured to liquefy CO_2.

[0030] As utilized herein, the terms "approximately," "about," "substantially", and similar terms are intended to have a broad meaning in harmony with the common and accepted usage by those of ordinary skill in the art to which the subject matter of this disclosure pertains. It should be understood by those of skill in the art who review this disclosure that these terms are intended to allow a description of certain features described and claimed without restricting the scope of these features to the precise numerical ranges provided. Accordingly, these terms should be interpreted as indicating that insubstantial or inconsequential modifications or alterations of the subject matter described and claimed are considered to be within the scope of the invention as recited in the appended claims.

[0031] The terms "coupled," "connected," and the like as used herein mean the joining of two members directly or indirectly to one another. Such joining may be stationary (e.g., permanent) or moveable (e.g., removable or releasable). Such joining may be achieved with the two members or the two members and any additional intermediate members being integrally formed as a single unitary body with one another or with the two members or the two members and any additional intermediate members being attached to one another.

[0032] References herein to the positions of elements (e.g., "top," "bottom," "above," "below," etc.) are merely used to describe the orientation of various elements in the Figures. It should be noted that the orientation of various elements may differ according to other exemplary embodiments, and that such variations are intended to be encompassed by the present disclosure.

[0033] It is important to note that the construction and arrangement of the various exemplary embodiments are illustrative only. Although only a few embodiments have been described in detail in this disclosure, those skilled in the art who review this disclosure will readily appreciate that many modifications are possible (e.g., variations in sizes, dimensions, structures, shapes and proportions of the various elements, values of parameters, mounting arrangements, use of materials, colors, orientations, etc.) without materially departing from the novel teachings and advantages of the subject matter described herein.

Claims

1. A fuel cell system (1) comprising:

a first fuel cell (10) comprising a first anode (14) and a first cathode (12), wherein the first anode is configured to output a first anode exhaust gas;
a first oxidizer (30) configured to receive the first anode exhaust gas and air from a first air supply (26), to react the first anode exhaust gas and

the air in a preferential oxidation reaction for conversion of CO to CO_2, and to output an oxidized gas;
a second fuel cell (40) configured to act as an electrochemical hydrogen separator, the second fuel cell comprising:

a second anode (44) configured to receive the oxidized gas from the first oxidizer and to output a second anode exhaust gas; and
a second cathode (42) configured to output a hydrogen stream; and

a condenser (60) configured to receive the second anode exhaust gas and to separate water and CO_2.

2. The fuel cell system of claim 1, wherein the condenser outputs CO_2, and further comprising a compressor (62) configured to receive and liquefy the CO_2 output from the condenser.

3. The fuel cell system of claim 1 or 2, further comprising a second oxidizer (52) configured to receive a first portion of the hydrogen stream from the second cathode and air from a second air supply, and to output an oxidized hydrogen stream.

4. The fuel cell system of claim 3, further comprising a heat exchanger (56) configured to receive and transfer heat from the oxidized hydrogen stream to a cathode inlet stream received by the first cathode.

5. The fuel cell system of claim 3, wherein the first anode is configured to receive a second portion of the hydrogen stream from the second cathode.

6. The fuel cell system of claim 1 or 2, further comprising:

a first heat exchanger (20) configured to receive and cool the first anode exhaust gas and output a first partially-cooled gas;
a first CO shift reactor (21) configured to receive the first partially-cooled gas, to perform a first CO shift reaction at a first temperature on the first partially-cooled gas, and to output a first shifted gas;
a second heat exchanger (22) configured to receive and cool the first shifted gas, and to output a second partially-cooled gas;
a second CO shift reactor (23) configured to receive the second partially-cooled gas, to perform a second CO shift reaction at a second temperature on the second partially-cooled gas, and to output a second shifted gas; and
a third heat exchanger (24) configured to receive and cool the second shifted gas, and to output a cooled gas;
wherein the first anode exhaust gas received at the first oxidizer is the cooled gas output from the third heat exchanger; and
wherein the first temperature is higher than the second temperature.

7. A method of processing fuel cell exhaust in the fuel cell system of claim 1, the method comprising:

at the first oxidizer (30), receiving the first anode exhaust gas from the first anode (14) and air from the first air supply (26);
outputting the oxidized gas from the first oxidizer;
at the second fuel cell (40), receiving the oxidized gas at the second anode (44), electrochemically separating hydrogen in the oxidized gas, outputting the hydrogen stream from the second cathode (42), and outputting the second anode exhaust gas from the second anode.

8. The method of claim 7, further comprising at the condenser (60), receiving the second anode exhaust gas and separating water and CO_2 in the second anode exhaust gas.

9. The method of claim 7 or 8, further comprising cooling the oxidized gas in a heat exchanger (32) prior to feeding the oxidized gas to the second anode.

10. A method of processing fuel cell exhaust in the fuel cell system of claim 2, the method comprising:

at the first oxidizer (30), receiving the first anode exhaust gas from the first anode (14) and air from the first air supply (26);
outputting the oxidized gas from the first oxidizer;
at the second fuel cell (40), receiving the oxidized gas at the second anode (44), electrochemically separating hydrogen in the oxidized gas, outputting the hydrogen stream from the second cathode (42), and outputting the second anode exhaust gas from the second anode;
at the condenser (60), receiving the second anode exhaust gas and separating water and CO_2 in the second anode exhaust gas; and
at the compressor (62), receiving the CO_2 from the condenser and outputting liquefied CO_2.

11. The method of claim 10, further comprising cooling the oxidized gas in a heat exchanger (32) prior to feeding the oxidized gas to the second anode.

12. A method of processing fuel cell exhaust in the fuel cell system of claim 6, the method comprising:

at the first oxidizer (30), receiving the first anode exhaust gas from the first anode (14) and air from the first air supply (26);
outputting the oxidized gas from the first oxidizer;
at the second fuel cell (40), receiving the oxidized gas at the second anode (44), electrochemically separating hydrogen in the oxidized gas, outputting the hydrogen stream from the second cathode (42), and outputting the second anode exhaust gas from the second anode;
at the first heat exchanger (20), cooling the first anode exhaust gas and outputting the first partially-cooled gas;
at the first CO shift reactor (21), performing a first CO shift reaction at the first temperature on the first partially-cooled gas and outputting the first shifted gas;
at the second heat exchanger (22), cooling the first shifted gas and outputting the second partially-cooled gas;
at the second CO shift reactor (23), performing the second CO shift reaction at the second temperature on the second partially-cooled gas and outputting the second shifted gas; and

at the third heat exchanger (24), cooling the second shifted gas and outputting the cooled gas.

13. The method of claim 12, further comprising cooling the oxidized gas in a fourth heat exchanger (32) prior to feeding the oxidized gas to the second anode.

14. A method of processing fuel cell exhaust in the fuel cell system of claim 3, the method comprising:

at the first oxidizer (30), receiving the first anode exhaust gas from the first anode (14) and air from the first air supply (26);
outputting the oxidized gas from the first oxidizer;
at the second fuel cell (40), receiving the oxidized gas at the second anode (44), electrochemically separating hydrogen in the oxidized gas, outputting the hydrogen stream from the second cathode (42), and outputting the second anode exhaust gas from the second anode;
at the second oxidizer (52), receiving the first portion of the hydrogen stream and air from the second air supply and outputting the oxidized hydrogen stream; and
transferring, by a heat exchanger (56), heat from the oxidized hydrogen stream to the cathode inlet stream received by the first cathode.

15. The method of claim 14, further comprising cooling the oxidized gas in a heat exchanger (32) prior to feeding the oxidized gas to the second anode.

Patentansprüche

1. Brennstoffzellensystem (1), umfassend:

eine erste Brennstoffzelle (10), die eine erste Anode (14) und eine erste Kathode (12) umfasst, wobei die erste Anode gestaltet ist, ein erstes Anodenabgas auszugeben;
einen ersten Oxidator (30), der gestaltet ist, das erste Anodenabgas und Luft von einer ersten Luftzuleitung (26) zu empfangen, das erste Anodenabgas und die Luft in einer bevorzugten Oxidationsreaktion zur Umwandlung von CO zu CO_2 zur Reaktion zu bringen und ein oxidiertes Gas auszugeben;
eine zweite Brennstoffzelle (40), die gestaltet ist, als ein elektrochemischer Wasserstoffabscheider zu dienen, wobei die zweite Brennstoffzelle umfasst;

eine zweite Anode (44), die gestaltet ist, das oxidierte Gas von dem ersten Oxidator zu empfangen und ein zweites Anodenabgas auszugeben; und
eine zweite Kathode (42), die gestaltet ist, einen Wasserstoffstrom auszugeben; und

einen Kondensator (60), der gestaltet ist, das zweite Anodenabgas zu empfangen und Wasser und CO_2 zu trennen.

2. Brennstoffzellensystem nach Anspruch 1, wobei der Kondensator CO_2 ausgibt, und weiter umfassend einen Kompressor (62), der gestaltet ist, das CO_2, das von dem Kondensator ausgegeben wird, zu empfangen und zu verflüssigen.

3. Brennstoffzellensystem nach Anspruch 1 oder 2, weiter umfassend einen zweiten Oxidator (52), der gestaltet ist, einen ersten Teil des Wasserstoffstroms von der zweiten Kathode und Luft von einer zweiten Luftzuleitung zu empfangen und einen oxidierten Wasserstoffstrom auszugeben.

4. Brennstoffzellensystem nach Anspruch 3, weiter umfassend einen Wärmetauscher (56), der gestaltet ist, Wärme aus dem oxidierten Wasserstoffstrom zu empfangen und zu einem Kathodeneinlassstrom überzuführen, der durch die erste Kathode empfangen wird.

5. Brennstoffzellensystem nach Anspruch 3, wobei die erste Anode gestaltet ist, einen zweiten Teil des Wasserstoffstroms von der zweiten Kathode zu empfangen.

6. Brennstoffzellensystem nach Anspruch 1 oder 2, weiter umfassend:

einen ersten Wärmetauscher (20), der gestaltet ist, das erste Anodenabgas zu empfangen und zu kühlen und ein erstes teilweise gekühltes Gas auszugeben;
einen ersten CO-Konvertierungsreaktor (21), der gestaltet ist, das erste teilweise gekühlte Gas zu empfangen, eine erste CO-Konvertierungsreaktion bei einer ersten Temperatur an dem ersten teilweise gekühlten Gas durchzuführen und ein erstes konvertiertes Gas auszugeben;
einen zweiten Wärmetauscher (22), der gestaltet ist, das erste konvertierte Gas zu empfangen und zu kühlen und ein zweites teilweise gekühltes Gas auszugeben;
einen zweiten CO-Konvertierungsreaktor (23), der gestaltet ist, das zweite teilweise gekühlte Gas zu empfangen, eine zweite CO-Konvertierungsreaktion bei einer zweiten Temperatur an dem zweiten teilweise gekühlten Gas durchzuführen und ein zweites konvertiertes Gas auszugeben; und
einen dritten Wärmetauscher (24), der gestaltet ist, das zweite konvertierte Gas zu empfangen und zu kühlen und ein gekühltes Gas auszugeben;
wobei das erste Anodenabgas, das bei dem ersten Oxidator empfangen wird, das gekühlte Gas ist, das von dem dritten Wärmetauscher ausgegeben wird; und
wobei die erste Temperatur höher als die zweite Temperatur ist.

7. Verfahren zum Verarbeiten eines Brennstoffzellenabgases in dem Brennstoffzellensystem nach Anspruch 1, wobei das Verfahren umfasst:

bei dem ersten Oxidator (30), Empfangen des ersten Anodenabgases von der ersten Anode (14) und von Luft von der ersten Luftzuleitung (26);
Ausgeben des oxidierten Gases von dem ersten Oxidator;
bei der zweiten Brennstoffzelle (40), Empfangen des oxidierten Gases bei der zweiten Anode (44), elektrochemisches Abtrennen von Wasserstoff in dem oxidierten Gas, Ausgeben des Wasserstoffstroms von der zweiten Kathode (42) und Ausgeben des zweiten Anodenabgases von der zweiten Anode.

8. Verfahren nach Anspruch 7, weiter umfassend bei dem Kondensator (60), Empfangen des zweiten Anodenabgases und Trennen von Wasser und CO_2 in dem zweiten Anodenabgas.

9. Verfahren nach Anspruch 7 oder 8, weiter umfassend Kühlen des oxidierten Gases in einem Wärmetauscher (32) vor Einspeisen des oxidierten Gases in die zweite Anode.

10. Verfahren zum Verarbeiten eines Brennstoffzellenabgases in dem Brennstoffzellensystem nach Anspruch 2, wobei das Verfahren umfasst:

bei dem ersten Oxidator (30), Empfangen des ersten Anodenabgases von der ersten Anode (14) und von Luft von der ersten Luftzuleitung (26);
Ausgeben des oxidierten Gases von dem ersten Oxidator;
bei der zweiten Brennstoffzelle (40), Empfangen des oxidierten Gases bei der zweiten Anode (44), elektrochemisches Abtrennen von Wasserstoff in dem oxidierten Gas, Ausgeben des Wasserstoffstroms von der zweiten Kathode (42) und Ausgeben des zweiten Anodenabgases von der zweiten Anode;
bei dem Kondensator (60), Empfangen des zweiten Anodenabgases und Trennen von Wasser und CO_2 in dem zweiten Anodenabgas; und
bei dem Kompressor (62), Empfangen des CO_2 von dem Kondensator und Ausgeben von verflüssigtem CO_2.

11. Verfahren nach Anspruch 10, weiter umfassend Kühlen des oxidierten Gases in einem Wärmetauscher (32) vor Einspeisen des oxidierten Gases in die zweite Anode.

12. Verfahren zum Verarbeiten eines Brennstoffzellenabgases in dem Brennstoffzellensystem nach Anspruch 6, wobei das Verfahren umfasst:

bei dem ersten Oxidator (30), Empfangen des ersten Anodenabgases von der ersten Anode (14) und von Luft von der ersten Luftzuleitung (26);
Ausgeben des oxidierten Gases von dem ersten Oxidator;
bei der zweiten Brennstoffzelle (40), Empfangen des oxidierten Gases bei der zweiten Anode (44), elektrochemisches Abtrennen von Wasserstoff in dem oxidierten Gas, Ausgeben des Wasserstoffstroms von der zweiten Kathode (42) und Ausgeben des zweiten Anodenabgases von der zweiten Anode;
bei dem ersten Wärmetauscher (20), Kühlen des ersten Anodenabgases und Ausgeben des ersten teilweise gekühlten Gases;
bei dem ersten CO-Konvertierungsreaktor (21), Durchführen einer ersten CO-Konvertierungsreaktion bei der ersten Temperatur an dem ersten teilweise gekühlten Gas und Ausgeben des ersten konvertierten Gases;
bei dem zweiten Wärmetauscher (22), Kühlen

des ersten konvertierten Gases und Ausgeben des zweiten teilweise gekühlten Gases;
bei dem zweiten CO-Konvertierungsreaktor (23), Durchführen einer zweiten CO-Konvertierungsreaktion bei der zweiten Temperatur an dem zweiten teilweise gekühlten Gas und Ausgeben des zweiten konvertierten Gases; und
bei dem dritten Wärmetauscher (24), Kühlen des zweiten konvertierten Gases und Ausgeben des gekühlten Gases.

13. Verfahren nach Anspruch 12, weiter umfassend Kühlen des oxidierten Gases in einem vierten Wärmetauscher (32) vor Einspeisen des oxidierten Gases in die zweite Anode.

14. Verfahren zum Verarbeiten eines Brennstoffzellenabgases in dem Brennstoffzellensystem nach Anspruch 3, wobei das Verfahren umfasst:

bei dem ersten Oxidator (30), Empfangen des ersten Anodenabgases von der ersten Anode (14) und von Luft von der ersten Luftzuleitung (26);
Ausgeben des oxidierten Gases von dem ersten Oxidator;
bei der zweiten Brennstoffzelle (40), Empfangen des oxidierten Gases bei der zweiten Anode (44), elektrochemisches Abtrennen von Wasserstoff in dem oxidierten Gas, Ausgeben des Wasserstoffstroms von der zweiten Kathode (42) und Ausgeben des zweiten Anodenabgases von der zweiten Anode;
bei dem zweiten Oxidator (52), Empfangen des ersten Teils des Wasserstoffstroms und von Luft von der zweiten Luftzuleitung und Ausgeben des oxidierten Wasserstoffstroms; und
Überführen, durch einen Wärmetauscher (56), von Wärme von dem oxidierten Wasserstoffstrom zu dem Kathodeneinlassstrom, der durch die erste Kathode empfangen wird.

15. Verfahren nach Anspruch 14, weiter umfassend Kühlen des oxidierten Gases in einem Wärmetauscher (32) vor Einspeisen des oxidierten Gases in die zweite Anode.

Revendications

1. Système de pile à combustible (1) comprenant :

une première pile à combustible (10) comprenant une première anode (14) et une première cathode (12), dans lequel la première anode est configurée pour sortir un premier gaz d'échappement d'anode ;
un premier oxydant (30) configuré pour recevoir le premier gaz d'échappement d'anode et de l'air provenant d'une première alimentation en air (26), pour faire réagir le premier gaz d'échappement d'anode et l'air lors d'une réaction d'oxydation préférentielle pour conversion de CO en CO_2, et pour sortir un gaz oxydé ;
une deuxième pile à combustible (40) configurée pour servir de séparateur d'hydrogène électrochimique, la deuxième pile à combustible comprenant :

une deuxième anode (44) configurée pour recevoir le gaz oxydé provenant du premier oxydant et pour sortir un deuxième gaz d'échappement d'anode ; et
une deuxième cathode (42) configurée pour sortir un flux d'hydrogène ; et

un condenseur (60) configuré pour recevoir le deuxième gaz d'échappement d'anode et pour séparer l'eau et le CO_2.

2. Système de pile à combustible selon la revendication 1, dans lequel le condenseur sort du CO_2, et comprenant en outre un compresseur (62) configuré pour recevoir et liquéfier le CO_2 sorti du condenseur.

3. Système de pile à combustible selon la revendication 1 ou 2, comprenant en outre un deuxième oxydant (52) configuré pour recevoir une première partie du flux d'hydrogène en provenance de la deuxième cathode et de l'air en provenance d'une deuxième alimentation en air, et pour sortir un flux d'hydrogène oxydé.

4. Système de pile à combustible selon la revendication 3, comprenant en outre un échangeur de chaleur (56) configuré pour recevoir et transférer de la chaleur depuis le flux d'hydrogène oxydé vers un flux d'entrée de cathode reçu par la première cathode.

5. Système de pile à combustible selon la revendication 3, dans lequel la première anode est configurée pour recevoir une deuxième partie du flux d'hydrogène depuis la deuxième cathode.

6. Système de pile à combustible selon la revendication 1 ou 2, comprenant en outre :

un premier échangeur de chaleur (20) configuré pour recevoir et refroidir le premier gaz d'échappement d'anode et sortir un premier gaz partiellement refroidi ;
un premier réacteur-convertisseur de CO (21) configuré pour recevoir le premier gaz partiellement refroidi, pour effectuer une première réaction de conversion de CO à une première température sur le premier gaz partiellement refroi-

di, et pour sortir un premier gaz converti ;
un deuxième échangeur de chaleur (22) configuré pour recevoir et refroidir le premier gaz converti, et pour sortir un deuxième gaz partiellement refroidi ;
un deuxième réacteur-convertisseur de CO (23) configuré pour recevoir le deuxième gaz partiellement refroidi, pour effectuer une deuxième réaction de conversion de CO à une deuxième température sur le deuxième gaz partiellement refroidi, et pour sortir un deuxième gaz converti ; et
un troisième échangeur de chaleur (24) configuré pour recevoir et refroidir le deuxième gaz converti, et pour sortir un gaz refroidi ;
dans lequel le premier gaz d'échappement d'anode reçu au niveau du premier oxydant est le gaz refroidi sorti du troisième échangeur de chaleur ; et
dans lequel la première température est supérieure à la deuxième température.

7. Procédé de traitement d'échappement de pile à combustible dans le système de pile à combustible selon la revendication 1, le procédé comprenant :

au niveau du premier oxydant (30), la réception du premier gaz d'échappement d'anode provenant de la première anode (14) et d'air provenant de la première alimentation en air (26) ;
la sortie du gaz oxydé provenant du premier oxydant ;
au niveau de la deuxième pile à combustible (40), la réception du gaz oxydé au niveau de la deuxième anode (44), la séparation électrochimique d'hydrogène dans le gaz oxydé, la sortie du flux d'hydrogène de la deuxième cathode (42) et la sortie du deuxième gaz d'échappement d'anode de la deuxième anode.

8. Procédé selon la revendication 7, comprenant en outre au niveau du condenseur (60), la réception du deuxième gaz d'échappement d'anode et la séparation de l'eau et du CO_2 dans le deuxième gaz d'échappement d'anode.

9. Procédé selon la revendication 7 ou 8, comprenant en outre le refroidissement du gaz oxydé dans un échangeur de chaleur (32) avant l'acheminement du gaz oxydé vers la deuxième anode.

10. Procédé de traitement d'échappement de pile à combustible dans le système de pile à combustible selon la revendication 2, le procédé comprenant :

au niveau du premier oxydant (30), la réception du premier gaz d'échappement d'anode en provenance de la première anode (14) et d'air en provenance de la première alimentation en air (26) ;
la sortie du gaz oxydé du premier oxydant ;
au niveau de la deuxième pile à combustible (40), la réception du gaz oxydé au niveau de la deuxième anode (44), la séparation électrochimique d'hydrogène dans le gaz oxydé, la sortie du flux d'hydrogène de la deuxième cathode (42) et la sortie du deuxième gaz d'échappement d'anode de la deuxième anode ;
au niveau du condenseur (60), la réception du deuxième gaz d'échappement d'anode et la séparation de l'eau et du CO_2 dans le deuxième gaz d'échappement d'anode ; et
au niveau du compresseur (62), la réception du CO_2 en provenance du condenseur et la sortie de CO_2 liquéfié.

11. Procédé selon la revendication 10, comprenant en outre le refroidissement du gaz oxydé dans un échangeur de chaleur (32) avant l'acheminement du gaz oxydé vers la deuxième anode.

12. Procédé de traitement d'échappement de pile à combustible dans le système de pile à combustible selon la revendication 6, le procédé comprenant :

au niveau du premier oxydant (30), la réception du premier gaz d'échappement d'anode en provenance de la première anode (14) et d'air en provenance de la première alimentation en air (26) ;
la sortie du gaz oxydé du premier oxydant ;
au niveau de la deuxième pile à combustible (40), la réception du gaz oxydé au niveau de la deuxième anode (44), la séparation électrochimique d'hydrogène dans le gaz oxydé, la sortie du flux d'hydrogène de la deuxième cathode (42) et la sortie du deuxième gaz d'échappement d'anode de la deuxième anode ;
au niveau du premier échangeur de chaleur (20), le refroidissement du premier gaz d'échappement d'anode et la sortie du premier gaz partiellement refroidi ;
au niveau du premier réacteur-convertisseur de CO (21), la réalisation d'une première réaction de conversion de CO à la première température sur le premier gaz partiellement refroidi et la sortie du premier gaz converti ;
au niveau du deuxième échangeur de chaleur (22), le refroidissement du premier gaz converti et la sortie du deuxième gaz partiellement refroidi ;
au niveau du deuxième réacteur-convertisseur de CO (23), la réalisation de la deuxième réaction de conversion de CO à la deuxième température sur le deuxième gaz partiellement refroidi et la sortie du deuxième gaz converti ; et

au niveau du troisième échangeur de chaleur (24), le refroidissement du deuxième gaz converti et la sortie du gaz refroidi.

13. Procédé selon la revendication 12, comprenant en outre le refroidissement du gaz oxydé dans un quatrième échangeur de chaleur (32) avant l'acheminement du gaz oxydé vers la deuxième anode.

14. Procédé de traitement d'échappement de pile à combustible dans le système de pile à combustible selon la revendication 3, le procédé comprenant :

au niveau du premier oxydant (30), la réception du premier gaz d'échappement d'anode en provenance de la première anode (14) et d'air en provenance de la première alimentation en air (26) ;
la sortie du gaz oxydé du premier oxydant ;
au niveau de la deuxième pile à combustible (40), la réception du gaz oxydé au niveau de la deuxième anode (44), la séparation électrochimique d'hydrogène dans le gaz oxydé, la sortie du flux d'hydrogène de la deuxième cathode (42) et la sortie du deuxième gaz d'échappement d'anode de la deuxième anode ;
au niveau du deuxième oxydant (52), la réception de la première partie du flux d'hydrogène et d'air provenant de la deuxième alimentation en air et la sortie du flux d'hydrogène oxydé ; et
le transfert, par un échangeur de chaleur (56), de chaleur depuis le flux d'hydrogène oxydé vers le flux d'entrée de cathode reçu par la première cathode.

15. Procédé selon la revendication 14, comprenant en outre le refroidissement du gaz oxydé dans un échangeur de chaleur (32) avant l'acheminement du gaz oxydé vers la deuxième anode.

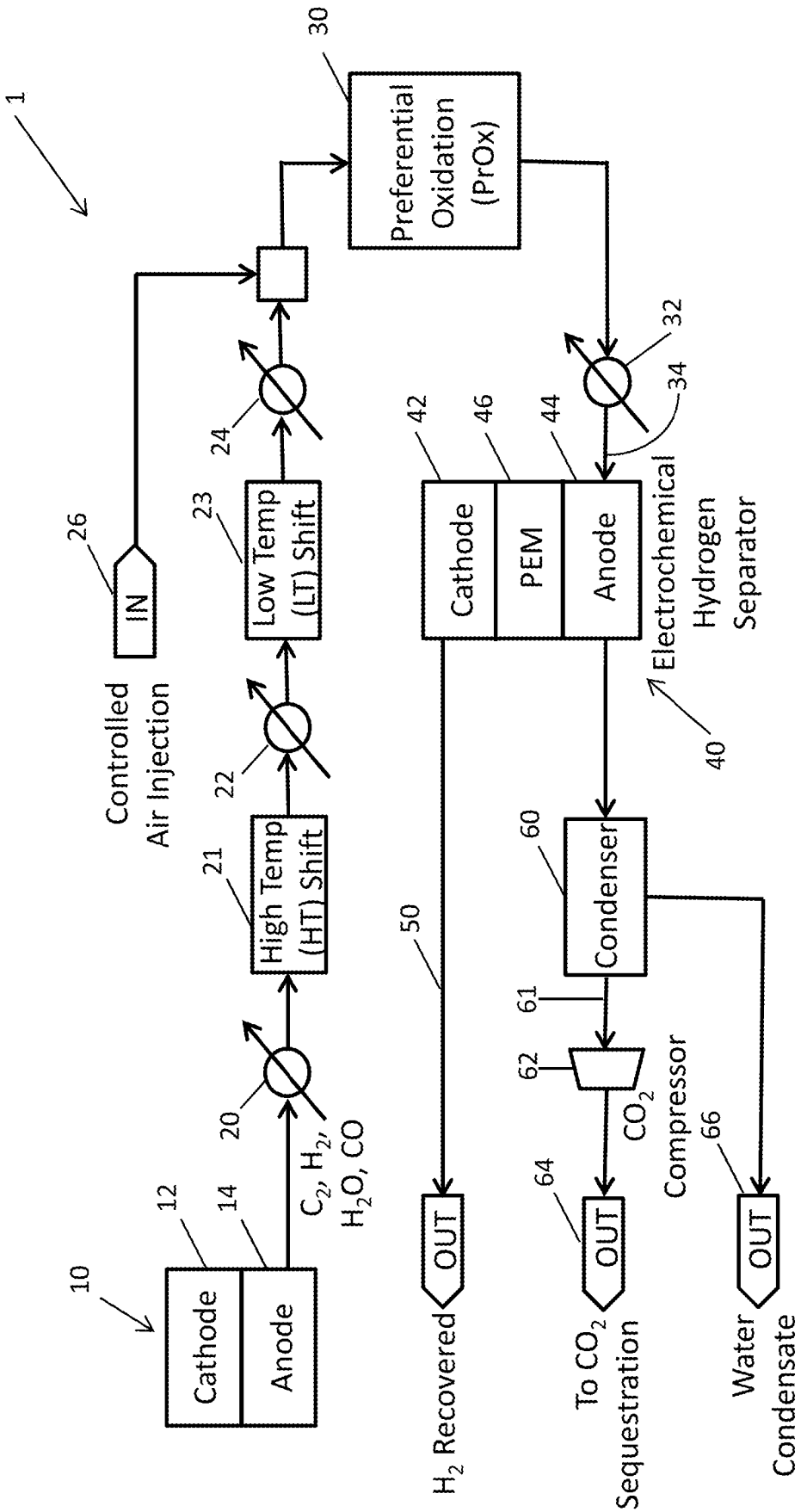
1
10
Cathode
Anode
12
14
20
C_2, H_2, H_2O, CO
High Temp (HT) Shift
21
22
Low Temp (LT) Shift
23
24
Controlled Air Injection
26
IN
30
Preferential Oxidation (PrOx)
32
34
Electrochemical Hydrogen Separator
40
42
Cathode
46
PEM
44
Anode
50
OUT
H_2 Recovered
60
Condenser
61
62
Compressor
CO_2
64
OUT
To CO_2 Sequestration
66
OUT
Water Condensate

FIG. 1

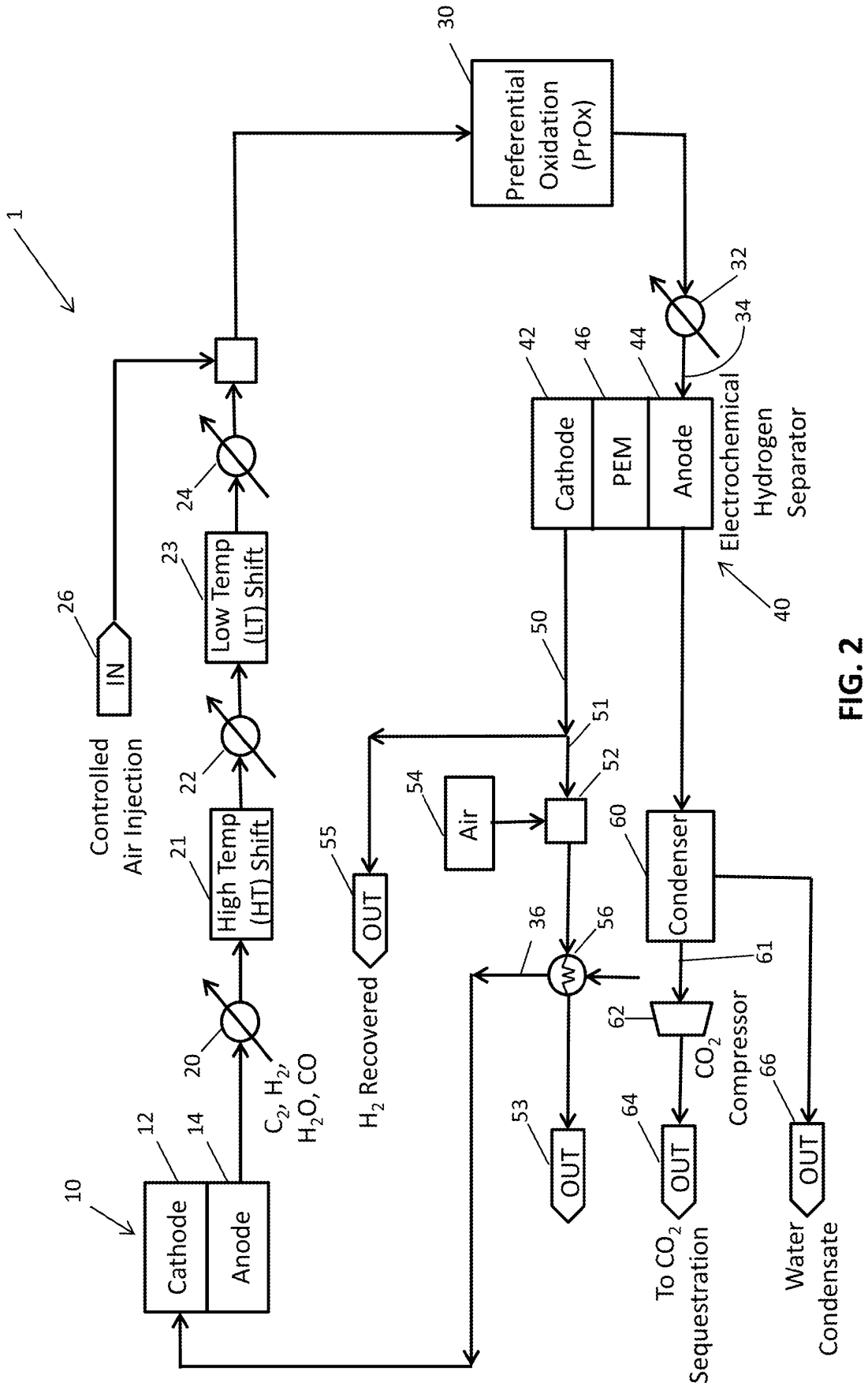
1
10
Cathode
Anode
12
14
20
C_2, H_2, H_2O, CO
High Temp (HT) Shift
21
22
Low Temp (LT) Shift
23
24
26
IN
Controlled Air Injection
30
Preferential Oxidation (PrOx)
32
34
Electrochemical Hydrogen Separator
40
Cathode
PEM
Anode
42
46
44
50
51
52
Air
54
55
OUT
H_2 Recovered
36
56
W
53
OUT
60
Condenser
61
62
CO_2 Compressor
64
OUT
To CO_2 Sequestration
66
OUT
Water Condensate

FIG. 2

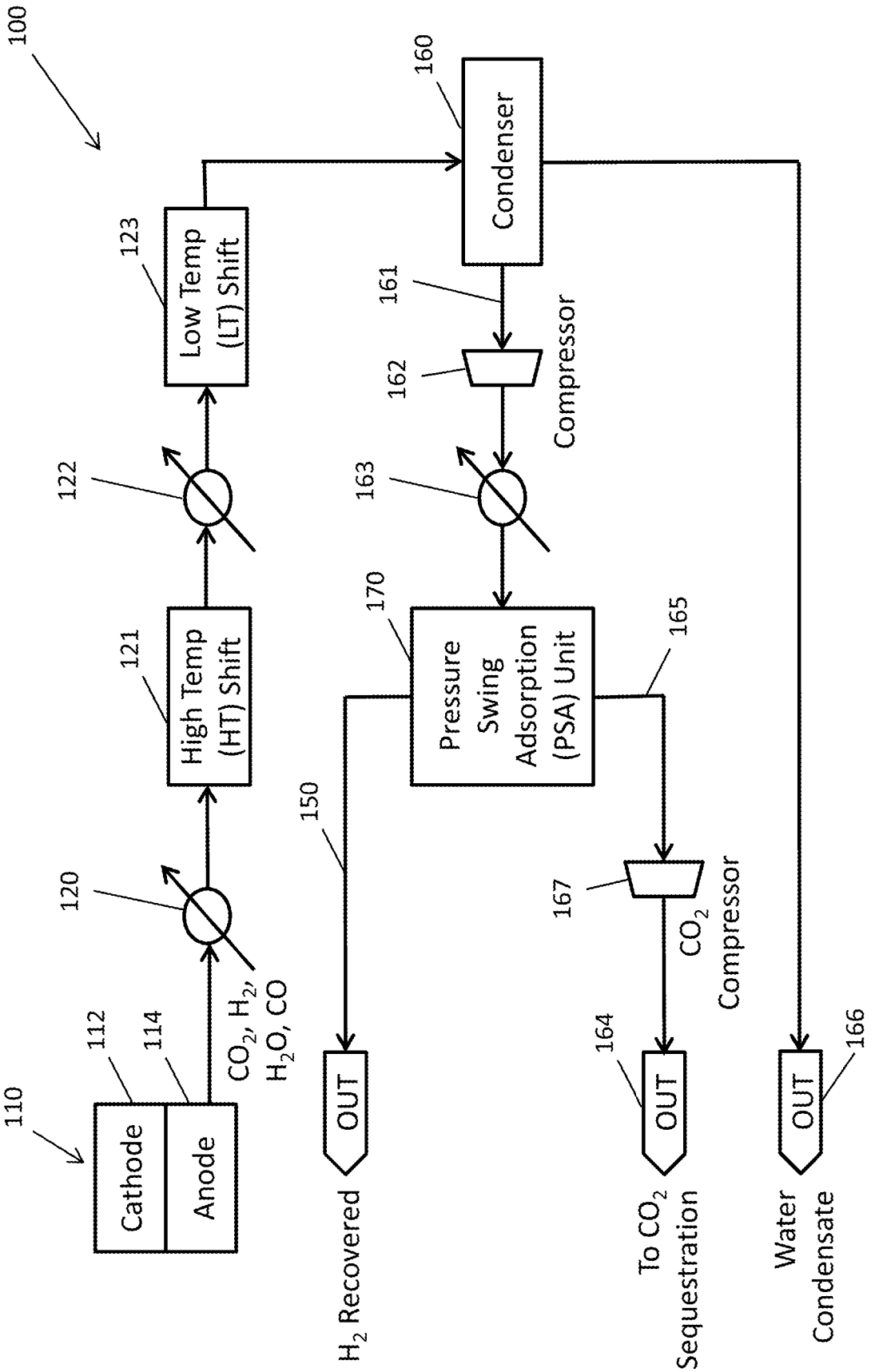
100
110
Cathode
Anode
112
114
CO_2, H_2, H_2O, CO
120
High Temp (HT) Shift
121
122
Low Temp (LT) Shift
123
Condenser
160
161
Compressor
162
163
Pressure Swing Adsorption (PSA) Unit
170
165
150
OUT
H_2 Recovered
167
CO_2 Compressor
164
OUT
To CO_2 Sequestration
OUT
Water Condensate
166

FIG. 3

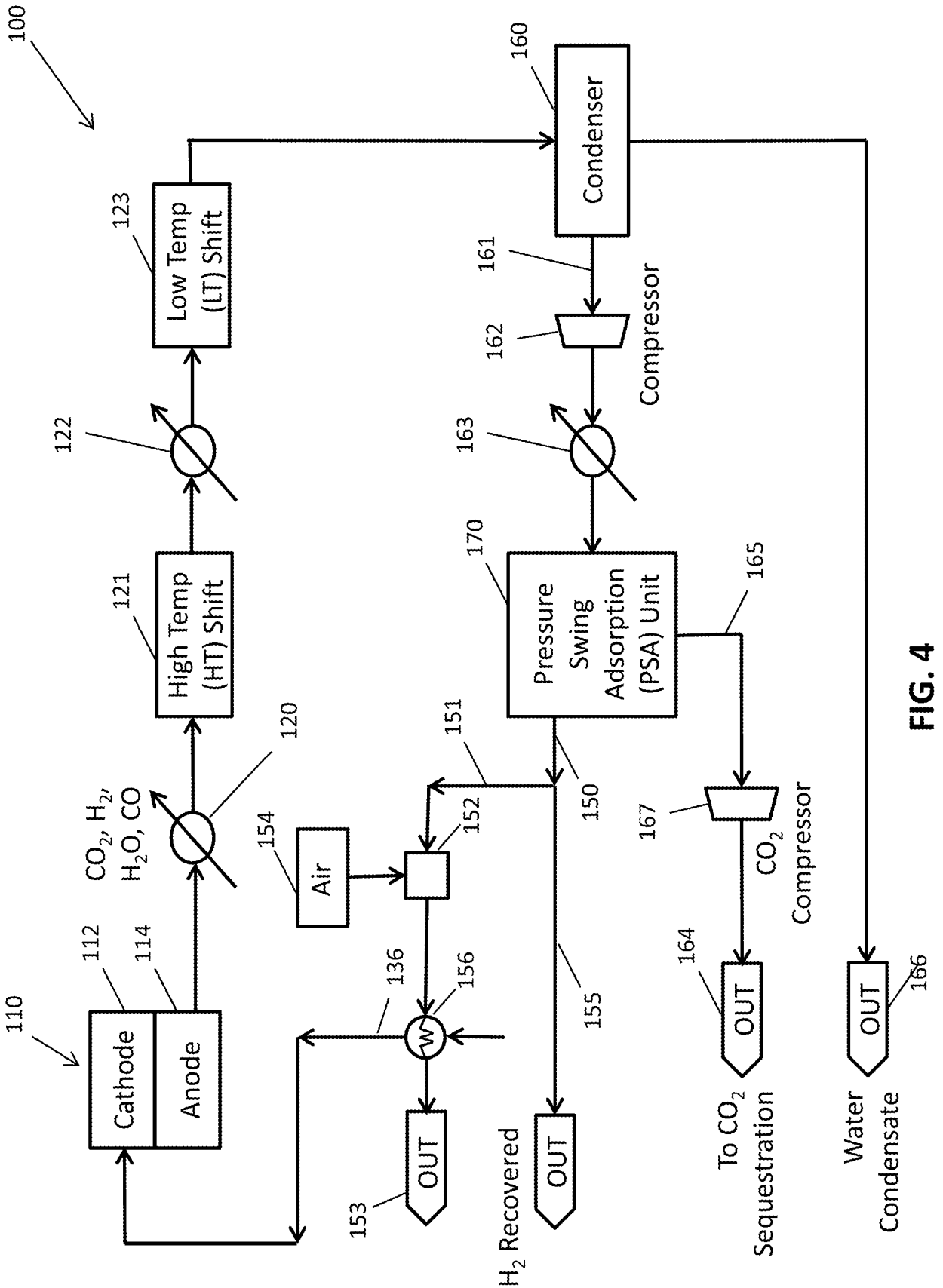
100
110
Cathode
Anode
112
114
120
CO_2, H_2, H_2O, CO
121
High Temp (HT) Shift
122
123
Low Temp (LT) Shift
160
Condenser
161
162
Compressor
163
170
Pressure Swing Adsorption (PSA) Unit
165
167
CO_2 Compressor
164
OUT
To CO_2 Sequestration
166
OUT
Water Condensate
150
151
152
154
Air
136
156
155
153
OUT
H_2 Recovered
OUT

FIG. 4

REFERENCES CITED IN THE DESCRIPTION

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Patent documents cited in the description

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- US 20040028979 A1 **[0004]**